

## **VIII. SUMMARY OF SENSITIVE RECEPTOR IMPACTS AND CONCLUSIONS**

As discussed in previous sections, it is clear that impacts to aquatic, terrestrial, and visual resources have occurred at Shenandoah National Park (SHEN) in response to human-made air pollution. We have varying confidence, however, in our understanding of the extent and magnitude of such effects within the park. Where selected resource components have been damaged (e.g., acidification of streamwaters, loss of sensitive aquatic biota, decreased calcium (Ca) to aluminum (Al) ratio in soil solution, ground level (tropospheric) ozone (O<sub>3</sub>) damage to foliage, ozone-mediated reduced tree growth, or occurrence of tree species), the range of response for a given type of receptor has been attributable to spatial and temporal variation in the sensitivity of the resources to adverse impacts more than to spatial variation in the severity of air pollution across the park. For example, it is primarily the streams that occur on siliciclastic bedrock that have been acidified and that have experienced loss of fish populations. Similarly, some plant species are more sensitive than others to damage at O<sub>3</sub> concentrations that currently occur in the park. In contrast, adverse impacts on visibility occur parkwide. However, the severity of the impact on visibility varies with season, as does the extent to which visibility degradation is associated with pollutants of anthropogenic origin.

### **A. AQUATIC ECOSYSTEMS**

Although baseline, pre-industrial resource conditions are not well known, we have a general understanding of the likely range of conditions that would occur in the absence of air pollution impacts. For example, it is clear that none of the streams within SHEN were acidic in pre-industrial times and the number of streams having ANC  $\leq 20$   $\mu\text{eq/L}$  was much lower than it is currently. MAGIC model estimates suggested that streams that currently exhibit streamwater ANC  $\leq 20$   $\mu\text{eq/L}$  experienced, on average, a decrease in ANC of 73  $\mu\text{eq/L}$  since pre-industrial times. Of the 14 streams modeled for this assessment, none had simulated pre-industrial streamwater ANC  $\leq 50$   $\mu\text{eq/L}$ , compared with 5 that currently have ANC  $\leq 26$   $\mu\text{eq/L}$ . Most streams that occur on siliciclastic bedrock now exhibit episodic decreases in streamwater ANC to values near or below zero during hydrological events. Model estimates suggest that the chronic ANC of streams was not sufficiently low for this to have been the case in pre-industrial times. In the most acid-sensitive streams, such episodic ANC depressions are accompanied by

pulses of increased acidity (decreased pH) and inorganic Al, which are toxic to many species of aquatic biota. Although episodic acidification is partly a natural process, it is also partly driven by sulfur (S) of atmospheric origin at SHEN, and it is superimposed on baseflow chemistry that is substantially more acidic than it was previously. This chronic and episodic loss of ANC has been accompanied by a loss of some fish species and other species of aquatic biota. Many streams have likely lost the more acid-sensitive species of fish and invertebrates. Species richness has declined, as has the condition of the acid-sensitive blacknose dace (*Rhinichthys atratulus*). In some streams, these impacts have been sufficiently large as to eliminate or reduce the population of brook trout (*Salvelinus fontinalis*), a rather acid-tolerant species.

## **B. TERRESTRIAL ECOSYSTEMS**

Tropospheric ozone has caused foliar damage to sensitive plant species within SHEN, including but not limited to milkweed (*Asclepias* spp.), black cherry (*Prunus serotina* Ehrh.), and yellow poplar (*Liriodendron tulipifera* L.). Little is known, however, about the relationship between visible foliar injury and the growth or vitality of the plants. Thus, it is not possible to judge fully what the implications of such visible damages might be. It is also suspected, but has not been demonstrated in the park, that O<sub>3</sub> may result in premature foliar color change and casting. The chronology of foliar color change is important at SHEN because many visitors come to the park in order to enjoy the autumn change of season.

Model simulations were conducted using the TREGRO and ZELIG models to project vegetation (individual tree and stand, respectively) growth in response to a range of future O<sub>3</sub> exposures in SHEN. The O<sub>3</sub> forest effects modeling analysis is an attempt to isolate the effects of O<sub>3</sub> from those of other stresses. Other stresses do occur, potentially exacerbating the relatively small, with the exception of white ash, direct growth effects of O<sub>3</sub> at current concentrations. Results suggested that reductions greater than about 1% in the growth of forest trees are not occurring under ambient O<sub>3</sub> exposure conditions. Among the tree species simulated, white ash (*Fraxinus americana*) was most sensitive, both as an individual tree, and as a component of a forest stand. TREGRO estimated about a 1% decrease in total growth of white ash over the three year 1997 to 1999 simulation period, due to ambient O<sub>3</sub> exposure throughout the park. Long-term (100-year) simulations with ZELIG suggested impacts less than about 1% on simulated basal area per hectare for all tree species simulated, except white ash. For other

species, simulated changes in basal area over time were influenced by other aspects of stand dynamics to a far greater extent than by O<sub>3</sub> exposure. For white ash, however, the basal area per ha within the chestnut oak forest type was projected to decline after 100 years from 1.2 m<sup>2</sup>/ha during the calibration period to about 1.1 m<sup>2</sup>/ha under the lowest simulated O<sub>3</sub> exposure and 0.6 m<sup>2</sup>/ha under continued ambient exposure. This is nearly a factor of two reduction in projected white ash basal area attributable to continued O<sub>3</sub> exposure at ambient levels.

Among the forest types simulated with ZELIG, however, there was little difference after 100 years in simulated results for overall stand basal area, density, or biomass in response to continued O<sub>3</sub> exposure at ambient levels as opposed to reduced O<sub>3</sub> exposures (to 20% of ambient five-month SUM06 exposure). Although white ash was simulated to experience reduced growth, its impact did not affect the simulated growth and development of any of the overall stands. This was because other species were projected to compensate for the projected adverse impacts on white ash. Nevertheless, protecting sensitive species, such as white ash, is an important NPS concern.

Forest soils within SHEN have probably acidified to some degree in response to acidic deposition. MAGIC model calibrations for 14 watersheds in SHEN suggested that the median decline in base saturation since pre-industrial times was 1.3%. For watersheds containing streams having ANC ≤ 20 µeq/L, the median simulated historical loss of base saturation was 1.2%. Compared with the median simulated pre-industrial value for base saturation (19%) for the watersheds that currently have ANC ≤ 20 µeq/L, this is not a large simulated change. Additional empirical data regarding soil acidification are needed, at least for the siliciclastic watersheds sampled as part of this effort, in order to more accurately evaluate the extent of soil acidification in the park.

It is not clear whether these estimates of past and/or future soil acidification have been, or will be, associated with adverse impacts on forest growth or health in SHEN. The park has no research to indicate that soil acidification has caused nutrient deficiencies in the forest to date or that the concentrations of inorganic Al in soil solution have increased to high enough levels to elicit toxicity responses. Soil solution empirical data in the park are limited, but do not suggest Ca:Al molar ratios near 1 (Table VI-12), the generally accepted threshold for protection of forest growth and health (c.f., Cronan and Griegal 1995). However, Nutrient Cycling Model (NuCM) simulations for White Oak Run suggested that the Ca:Al molar ratio in soil solution might

decrease in the future (by 2040) to levels below 1, even under substantially reduced S deposition (Sullivan et al. 2002b). Adverse forest health responses cannot be ruled out now or in the future, especially if acidic deposition levels remain high.

### **C. VISIBILITY**

The current visibility conditions at SHEN are severely degraded as compared with estimates for natural conditions in the park of about 184 km (115 mi). The annual average calculated light extinction at SHEN ( $107.0 \text{ Mm}^{-1}$ ) is approximately five times greater than the estimated annual average for natural conditions in the East ( $22.2 \text{ Mm}^{-1}$ ). As shown in Section V, the average visual range on the clearest days (Figure V-20) is presently only about 90 km, or about 30% of what it could be in the absence of anthropogenic air pollution (270 km). Similarly, current average conditions of the middle 20% of days and the average haziest conditions are, respectively, 25% and 14% of what they could be in the absence of air pollution. Visibility degradation is greatest in the summer months when park visitation is high, with visual ranges averaging 20 km (Table V-11). Whereas winter visibility conditions are generally best, winter visual range seldom exceeds 70 km. Average visual range in the autumn, another high visitation period, seldom exceeds 45 km.

Seasonal average calculated light extinction ranges from  $61.0 \text{ Mm}^{-1}$  during winter to  $193.5 \text{ Mm}^{-1}$  during summer. Seasonal variability in visibility is driven primarily by ammonium sulfate ( $[\text{NH}_4]_2\text{SO}_4$ ) extinction. Organics, fine soil, and coarse mass extinction contribute to seasonal variability to a lesser degree, but extinction due to light absorbing carbon and nitrate is similar among seasons at the park.

Calculated extinction for the clearest 20% of the days for March 1988 through February 2000 showed no consistent trend, with values ranging between about  $38 \text{ Mm}^{-1}$  and  $50 \text{ Mm}^{-1}$ . The clearest 20% days are substantially degraded by  $[\text{NH}_4]_2\text{SO}_4$  (51% of fine mass budget) and ammonium nitrate ( $\text{NH}_4\text{NO}_3$ ; 12% of fine mass budget; Figure V-20). The haziest 20% of the days for the same period showed a moderate improving (downward) trend, with values ranging between  $163 \text{ Mm}^{-1}$  and  $251 \text{ Mm}^{-1}$ . The fine mass budget on these haziest days is comprised largely of  $[\text{NH}_4]_2\text{SO}_4$  (72%), with only 2% being  $\text{NH}_4\text{NO}_3$  (Figure V-20).

## **D. CONCLUSIONS**

To date, and as this assessment illustrates, it appears that the following adverse effects have occurred to the following sensitive receptors:

- aquatic chemistry - chronic and episodic acidification of streamwaters, most importantly those occurring in watersheds underlain by siliciclastic, and to a lesser degree, granitic bedrock
- aquatic biota - loss of sensitive species, changes in condition of sensitive species, reduction in species richness of fish and benthic insects
- forest health - O<sub>3</sub> damage to foliage, reduced growth and occurrence of white ash
- visibility - significant degradation of visual range and scenic quality relative to estimated natural conditions

In addition, it is possible, but has not been demonstrated, that soils have acidified in response to acidic deposition.

Additional and innovative measures will have to be implemented over time if continued progress is to be made toward the National Visibility Goal to reach natural conditions in Class I areas by 2064. Eastern states are required to submit State Implementation Plans to the U.S. EPA in 2008 that calculate the rate of progress needed to achieve the goal for each Class I area (using 2000-2004 ambient conditions as the baseline) and present the measures that will be adopted to make “reasonable progress” toward that goal through 2018. States must periodically assess (every 5 years) their rate of progress and, every 10 years, revise their plans in order to maintain reasonable progress toward the National Visibility Goal (see the discussion of the Regional Haze Regulation in Section I.B).

Similarly, it will be necessary for S deposition to be reduced substantially below current levels in order to prevent further acidification and associated biological impacts in acid-sensitive streams within SHEN. Emissions reductions required by the Clean Air Act Amendments will be sufficient to prevent further deterioration of some, but not all, acid-sensitive streams in the park (Table VII-8). Model analyses for this assessment suggested that recovery of all streams in the park to ANC levels above 20 µeq/L would occur within about 100 years if S deposition was reduced below about 5 kg S/ha/yr, which is less than 40% of the current deposition amount. It was projected that recovery of siliciclastic streams to ANC levels above 50 µeq/L by 2100 would require S deposition ranging from 1 kg/ha/yr (Meadow Run) to 6 kg/ha/yr (Paine Run) for all

siliciclastic sites except White Oak Run. For White Oak Run, it was projected that  $\text{ANC} = 50 \mu\text{eq/L}$  would not be attained by 2100 even if S deposition was reduced to 0.